EXPERIMENTAL METHODS FOR VALUING AESTHETICS AND HEALTH EFFECTS IN THE SOUTH COAST AIR BASIN: AN OVERVIEW

by

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SUMMARY

Benefit-cost analysis of air pollution control requires information on consumer's willingness to pay for clean air. Methodological development for valuing non-market goods has progressed substantially over the last few years. However, previous work in placing an economic value on air pollution control has not sorted out consumer valuations between aesthetic effects, acute and chronic health effects. In an attempt to fill this void, an experiment was conducted in the South Coast Air Basin of California. The first part of the experiment consisted of a survey questionnaire in which individuals were asked about their willingness to pay for clean air. Second, a property value study was conducted to provide a methodological cross-check for the survey. Comparability of the results was found in that individual's appeared to be willing to pay at least as much in higher prices for homes in clean air areas as they were willing to pay when asked in the survey.

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SECTION 1

INTRODUCTION

Several approaches for obtaining the value of non-market goods have been tried. Systematic comparisons of the results to check the validity and consistency of these approaches have been limited. This chapter attempts to compare two methodologies for estimating the benefits of environmental control, to address the component parts of benefit measures of air pollution control (i.e., health and aesthetics), and to provide specific estimates of the benefits of air pollution control to households for selected areas of the South Coast Air Basin of Southern California.

The two approaches to be compared and contrasted are the iterative bidding technique and the property value approach. The former asks the consumer in a highly structured hypothetical market to determine dollar values for alternative levels of the public good in question [Davis (1963); Kurz (1974); Bohm (1971); Bohm (1972); Randall, et. al., (1974); Brookshire, et. al., (1976); Rowe et.al., (forthcoming); Randall, et. al., (1978); Thayer and Schulze (1977); and Brookshire, et. al., (forthcoming)]. Property value studies in contrast to the direct determination of willingness to pay through surveys, depend upon the existence of a market data set to allow the derivation of willingness to pay [for example, Ridker and Henning (1967); Anderson and Crocker (1971); Deyak and Smith (1978); Steele (1972) and Wieand (1973)].

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The study area chosen for the experimental comparison was the South Coast Air Basin of Southern California. An advantage of this region is that the population has become well informed through the years of the causes of air quality deterioration, and the effects and scope of the problem. Thus in valuing the non-market good, air quality, the experiment was conducted with "market information" for individuals reasonably well developed.

Our principal conclusions can be summarized as follows:

Households in the property value study were willing to pay an average of $42 per month (in the form of home mortgage payments) for a 30% improvement in air quality.

Households in the iterative bidding (survey) study are willing to pay $29 per month for a 30% improvement in air quality.

The aesthetic valuation associated with a 30% improvement in air quality in the South Coast Air Basin ranged from 23% to 50% of the total valuation.

Health effects represent from 50% to 77% of the total valuation for 30% improvement in air quality in the South Coast Air Basin.

Previous research results indicating a lack of biases in utilizing survey instruments are supported by the iterative bidding study.

The results suggest that households are actually willing to pay (as determined in the property value study) what they state they will pay (as determined in the iterative bidding (survey) study).

The chapter first focuses upon a common theoretical framework that incorproates and relates the iterative bidding technique and the property value approach. Section 3 presents the paired sample methodology used in the South Coast Air Basin Study. In Section 4, the data collection mechanism for the iterative bidding process and the corresponding results are discussed. Section 5 presents the empirical results of the property value approach while Section 6 provides a comparison of the estimates from each approach.

SECTION 2

FRAMEWORK FOR VALUING NON-MARKET GOODS

The variety of approaches used to value public goods have lacked a common theoretical linkage. Whether the analysist has employed a survey approach, actual observed behavior or market prices, the results have been based on narrow theoretical structures which have little relationship to the others. Certain characteristics must exist in a common modeling structure. The theoretical framework presented here attempts to provide a unified analysis for comparison of alternative techniques involving public goods.

Individual consumer utility can be specified as a function of levels of activities, $A_1, \ldots, A_i, \ldots, A_n$ (where the subscripts denote either sites or different activities for a given sight) as a function of environmental quality for each environmentally related activity or site, $Q_1, \ldots, Q_i, \ldots, Q_n$ (where we take increases in Q_i as increasing environmental quality), and as a function of a composite commodity X. Utility is then a quasi-concave function,

$$U(A_1, \ldots, A_n; Q_1, \ldots, Q_n; X), \tag{1}$$

where $\partial U/\partial A_i = U_A^i \geq 0$, $\partial U/\partial Q_i = U_Q^i \geq 0$, and $\partial U/\partial X = U_X \geq 0$ so utility is increasing in A_i, Q_i, and X. Of course, a number of assumptions on the separability of U are obvious, given environmental quality is related to specific we focus on the <u>form</u> of an economic agent's marginal willingness to pay for environmental quality.

The budget constraint necessary to specify the individuals optimization problem is given as:

$$Y - \sum_{i=1}^{n} P_i A_i - X \geq 0 \tag{2}$$

or income Y minus the sum of expenditures on environmentally related activities $\sum_{i=1}^{n} P_i A_i$ (P_i is taken as the price of activity i which may, in fact, represent joint consumption of several market commodities) minus expenditures for the composite consumption commodity X (price is taken as unity to simplify the analysis).

For a given vector of environmental quality, a consumer or household will then choose to allocate activities such that (1) is maximized subject to (2) which in turn implies that:

$$\frac{U_A^i}{U_X} \leq P_i, \quad \left(\frac{U_A^i}{U_X} - P_i\right)A_i = 0, \quad A_i \geq 0 \qquad i = 1,2, \ldots, n \tag{3}$$

or the marginal rate of substitution between activity i and the composite commodity X equals the price of activity i - if that activity is chosen ($A_i > 0$). We, of course, assume $X > 0$.

To determine the marginal willingness to pay for environmental quality at a particular site, for example i = 1, we set utility as given in equation (1) equal to a constant and totally differentiate the resulting expression. By then taking the total differential of equation (2), setting $dQ_i = 0$ for $i \neq 1$ and by using (3) we obtain:

$$\frac{dY}{dQ_1} = \underbrace{\sum_{i=1}^{n} A_i \frac{dP_i}{dQ_1}}_{(a)} - \underbrace{\frac{U_Q'}{U_X}}_{(b)} \tag{4}$$

as the change in income necessary to offset a change in environmental quality at site 1. Another expression for dY/dQ_1 can be obtained by simply taking the total differential of the budget constraint, equation (2) (again setting $dQ_i = 0$ for $i \neq 1$):

$$\frac{dY}{dQ_1} = \underbrace{\sum_{i=1}^{n} A_i \frac{dP_i}{dQ_1}}_{(c)} + \underbrace{\sum_{i=1}^{n} P_i \frac{dA_i}{dQ_1}}_{(d)} + \underbrace{\frac{dX}{dQ_1}}_{(e)}. \tag{5}$$

presuming that the dA_i/dQ_1 are consistent with constant utility. Comparing the two expressions for marginal willingness to pay implies that since the terms (a) and (c) in equations (4) and (5) respectively, are identical that:

$$\sum_{i=1}^{n} P_i \frac{dA_i}{dQ_1} + \frac{dX}{dQ_1} = \frac{-U_Q'}{U_X} < 0 \tag{6}$$

so the sum of the terms (d) and (e) in equation (5) are negative.

The interpretation of (5) provides the basis for comparing the two methodologies. If the objective is to determine the marginal willingness to pay for environmental quality dY/dQ_1 , one obvious approach is to simply postulate in a survey instrument that Q_1 changes by a small amount, dQ and request information on the contingent willingness of the individual to either accept compensation for a decrease in quality or pay to prevent a decrease in quality. This is termed the iterative bidding technique.

In contrast to the iterative bidding approach, the hedonic approach, focusing on price effects of changes in environmental quality, effectively assumes both the allocation of some activities and other expenditures is invariant to changes in quality (dA_i/dQ_1 = 0, for some i, and dX/dQ = 0), but also that all prices other than P_1, the price associated with A, and in turn Q_1, remain fixed (dP_i/dQ_1 = 0, $V_i \neq 1$). Thus, from equation (5):

$$\frac{dY}{dQ_1} = A_1\frac{dP_1}{dQ_1} . \qquad (7)$$

As an example of this approach, consider a study which uses changes in property values of homes in clean versus polluted areas of a region as a measure of value of air quality. Serious questions must be raised, however, concerning the reality of the assumptions that other prices and levels of other activities are fixed.

Thus, the marginal willingness to pay of individuals for environmental quality can be determined as shown in our theoretical context by two approaches. First, individuals can be directly asked to provide their marginal willingness to pay, dY/dQ . Second, assuming the allocation of activities and expenditures is invariant to a quality change and assuming all prices but one are also invariant, the change in the single remaining price, dP_1, can be used to impute environmental benefits. Of the two approaches, the one which requires the, fewest a priori assumptions is the first.

A final point needs to be made with respect to non-marginal changes in environmental quality which require that proper measures of willingness to pay as opposed to marginal willingness to pay be utilized for comparing alternative methodologies. In the empirical studies presented below, individuals were asked to bid on non-marginal changes in air quality. These direct non-marginal bids are then compared to the changes in property values which are associated with a similar shift in environmental quality. What then is the theoretical relationship between the property value measure of willingness to pay as compared to the survey approach? If we assume that property values capture the entire willingness to pay for clean air, then Figure 1 provides an answer.

In Figure 1, monthly rent or equivalent monthly payments for owner occupied homes is plotted on the vertical axis. On the horizontal axis we plot air quality. Now, hedonic price theory implies that if people prefer clean air, rents should rise across a region (everything else held constant) as the air quality improves. This results in the rent gradient denoted by R in Figure 1. Individuals with different preferences over different levels of air quality will locate at different points along R. Thus, an individual A with indifference curve I chooses to live in an area with poor air quality, Q_1, and pay lower rent.
indifference curve 1_B will choose to live in an area with better air quality, Q_2, but must give up income to pay the higher associated rent. Now, if we ask individual B located at air quality level Q_2 what is the maximum he or she is

willing to pay to improve air quality at that location to Q_3, the individual should be willing to pay $B per month as shown in Figure 1.[3] Note, however, that if we compare the rents of air quality at location Q_2 to those at a location with improved air quality, Q_3, equivalent to that specified in the hypothetical question above, the rent difference is ΔR as shown in Figure 1 which exceeds the bid, B. This occurs because although the rent gradient gives the same valuation at the margin as the bid (the indifference curve I_B and the rent gradient R have the same slope at Q_2), when non-marginal changes in air quality are employed, the rent gradient moves across individuals of differing tastes with respect to air quality. In other words, the rent gradient may overestimate willingness to pay because higher rents in clean air areas are associated with specially sensitive individuals and not with the general population.[1] Thus, although as we have shown in preceding arguments, property value studies may underestimate marginal willingness to pay if other prices than property values "pick up" some of the value of clear air, they may also overestimate non-marginal or total willingness to pay as a result of non-homogeneous preferences.

FIGURE 1

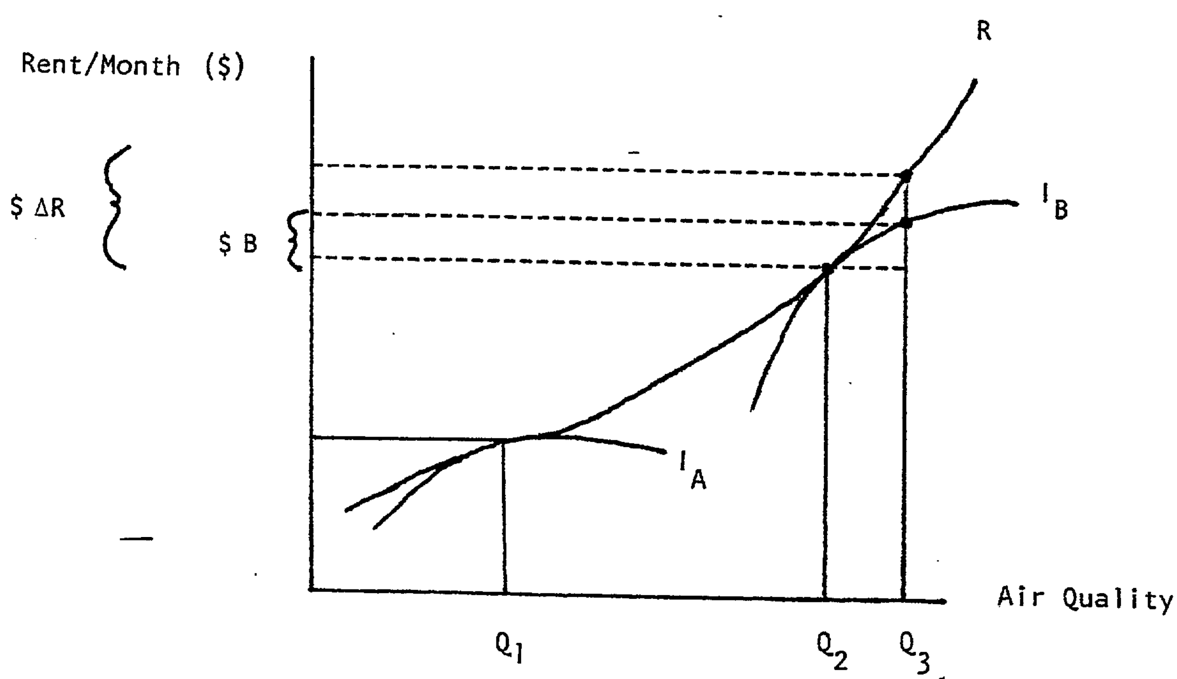
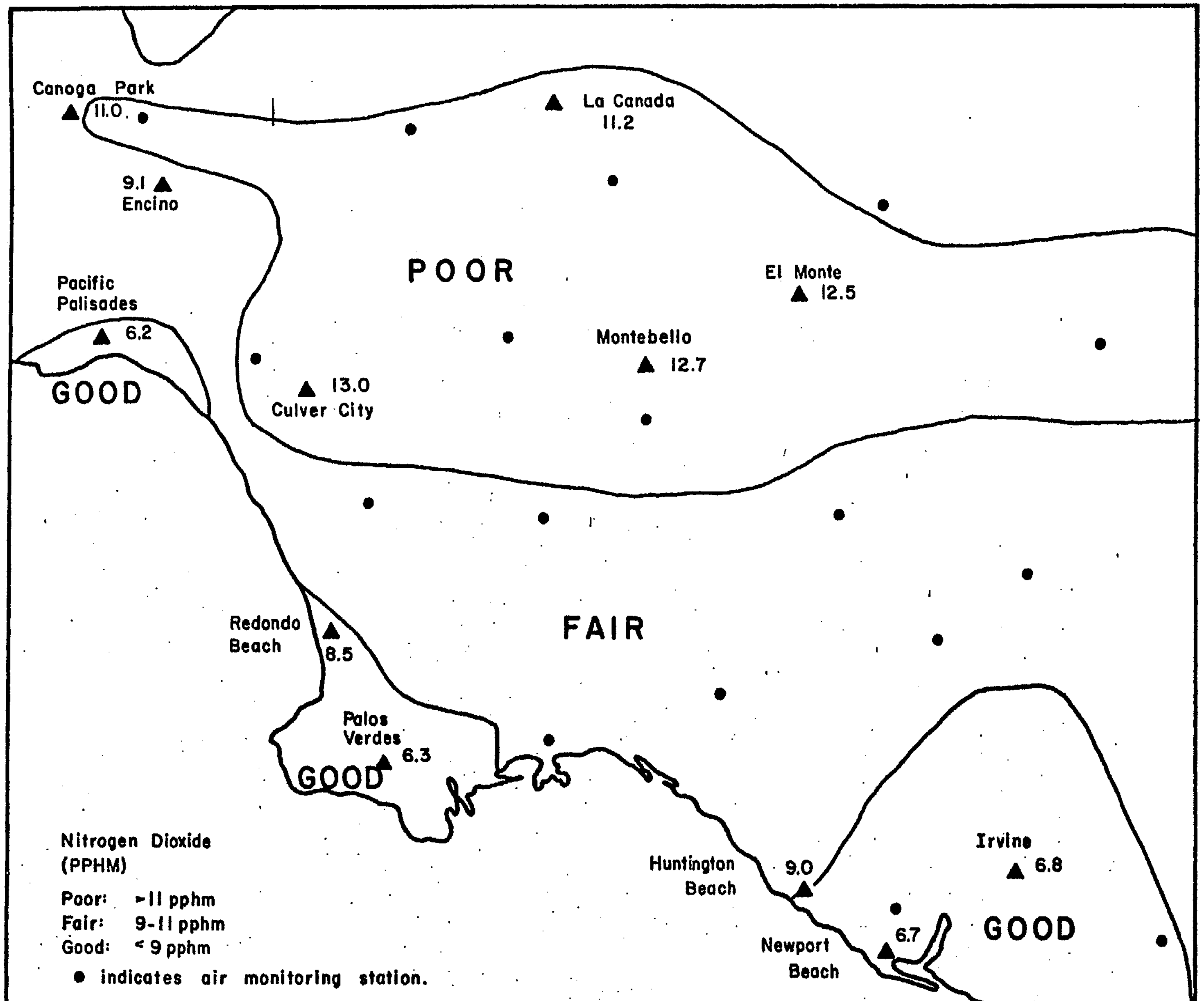


Figure 2

Isopleths for Nitrogen Dioxide Levels in the South Coast Air Basin



SECTION 3

A PAIRED SAMPLE METHODOLOGICAL AREA APPROACH

In order to allow a cross-check between the iterative bidding technique and the property value study, a commom sampling methodology is needed. This is important for the property value study which must attempt to control for as many exogeneous variables as possible. Given the micro nature of the property value data set, and that the iterative bidding technique employs primary data collection, a common sampling methodology developed so the results would be comparable.

The approach chosen was to form pairs of census tracts in the South Coast Air Basin (SCAB) holding socioeconomic characteristics constant yet allowing a variation in air quality across pairs. Throughout the SCAB air monitoring stations are located, which provide readings of Ozone (O_3), Nitrogen Dioxide (NO_2), Nitric Oxide (NO_x), Carbon Monoxide (CO), Hydrocarbons (HC), Sulfer Dioxide (SO_2), particulate matter, wind and in some cases lead (Pb), and oxidant levels. The goal was to relate as closely as possible the readings of these constituents of air pollution to the surrounding census tract populations.

Given the locations of the air monitoring stations in the SCAB, the surrounding census tracts were identified using the Department of Commerace's demographic information for three specific purposes: (1) to define the census tract parameters and characteristics; (2) to designate census tracts representative of the SMSA as a whole; and (3) to provide the means for matching census tracts in the test areas to similar census tracts in the control area. Figure 2 gives the location of air monitoring stations (•) and the paired areas (*) chosen for the sample plan. The isopleths depict for nitrogen dioxide levels: "poor" air quality (NO_2 greater than 11 pphm); "fair" air quality (9-11 pphm); and "good" air quality (less than 9 pphm).

The aim of the sampling procedure was to determine paired areas in the SCAB that are similar in all relevant characteristics except air quality. If the mean values of the relevant characteristics are not significantly different across areas, the difference in valuation of amenities and environmental health effects given by individual households in an area characterized by clean air versus the valuation given by an individual in an area characterized by diminished air quality should be due to the existence or non-existence of pollution in thier environment.

SECTION 4

THE ITERATIVE BIDDING STUDY

The two approaches employed in the methodological cross-check require significantly different data sets. This section outlines the structure necessary for employing the iterative bidding technique and presents an overview of the results.

The iterative bidding technique is a direct determination of economic values from data which represent responses of households to contingencies posted to them via a survey instrument. Given that air quality is a public good, the individual at a particular location has no choice as to the amount he consumes. The individual's problem is then one of responding to proposed contingencies.

How then are the relevant measures to be obtained? The Randall, et. al. (1974) study introduced several features which have for the most part been-retained in later iterative bidding studies.

A hypothetical market is established where alternative levels of provision of the air quality are described in quantity, quality, location and time dimensions. Wherever possible photograph sets and other props (i.e., the air quality isopleth map) are utilized to ensure uniform perception. The hypothetical market is defined in terms of exclusive mechanisms whereby the respondent is assured that all users of the good will pay equally (e.g., through tax increments, increments in the price of associated services, or charges collected in special funds). The payment method, called a vehicle, is specified and is chosen for its feasibility. The respondent reacts to prices (i.e., bids) posed by an enumerator. The price is varied iteratively, until the price at which the respondent's typical market experience, where he is confronted with specified goods at stated prices and must decide to buy or not to buy. 2

Thus, the iterative bidding process represents an attempt to establish a hypothetical market having many of the features of existing markets.

In this study the good termed air quality, was divided into its characteristic parts - aesthetic effects, acute health and chronic health effects. Previously no attempt to value the characteristic parts of a public good had been made. Each characteristic was bid upon in turn by the respondent. In every case the initiation point for the respondent was the existing situation as designated by location of their home. 3

Alternative payment vehicles were employed in the bidding process. Typically iterative bidding processes have chosen well-defined vehicles, However, vehicles themselves might introduce a confounding element into the bidding process. Thus, a more generalized version of a vehicle was employed using the notion of a lump sum payment in addition to a utility bill vehicle.

Alternative survey instrument formats included the bidding process being commenced with different characteristics in order to test for sequencing, alternative starting point bias, and varying time intervals for the clean-up projected in the contingent world.

Changes in air quality were defined to respondents by reference to maps similar to Figure 2. The subjective definitions of good, fair and poor air quality were meaningful and readily apparent to regional resident.

In addition, photographs for the aesthetic part of the bidding processes were employed to supplement the descriptive information provided to the respondent in establishing the hypothetical markets. For the aesthetic portion of this study, three sets of photographs corresponding to situations depicted as "good," "fair" and "poor" were used.

In order to develop the picture sets two observational paths from Griffith Observatory in Los Angeles were chosen: (1) toward downtown Los Angeles and (2) looking down Western Avenue. The approximate visibility (discernable objects in the distance not visible range) for picture set A (poor) is 2 miles, for picture set B (fair) is 12 miles and for picture set C (good) at 28 miles.

The results of the experiment form the basis of some simple statistical tests. The tests to be considered are whether:

1. the area mean bids are significantly different from zero;
2. the results indicate the existence of starting point, vehicle or sequencing bias;
3. the results indicate different bidding behavior when individuals were offered different completion dates for clean-up; and
4. the aesthetic, acute, chronic and total bids for the paired areas are significantly different.

Briefly, the t-tests regarding the hypothesis that area mean bids were statistically different from zero indicated that only for Montebello's chronic health bids was the null hypothesis rejected. Thus, we can initially infer that in all areas, the values individuals placed on the three characteristics of air quality under consideration tended to be non-zero.

A test of means was conducted between the monthly utility bill and the lump sum payment mechanism for the areas by characteristic bid and for the total bid. The null hypothesis set forth was that the mean bids were equal irrespective of the bidding vehicle. For the Montebello, Canoga Park, Encino, Huntington Beach, Newport Beach, Pacific Palisades, Palos Verdes, and Redondo Beach areas in the SCAB, the null hypothesis is accepted for the total bid. However, for Irvine, Culver City, La Canada, and El Monte, we reject the null hypothesis, at least at the 90% confidence level, for the total bid. No obvious reason exists at this point in time for this result. The principal problem area appears to be in the aesthetic bids.

A test to determine whether individuals bid differently within an area depending upon the projected clean-up date was conducted. The null hypothesis of this test was that the bids are equal no matter the completion date for the clean-up. The null hypothesis was rejected only in isolated cases such as Canoga Park. The implication of this result is that individuals appear not to view the magnitude of their bid being significantly determined by the proposed clean-up date.

Starting point bias results from the final bid being statistically related to the starting bid, i.e., the higher the starting point, the higher will be the final bid, thus suggesting a type of information bias. The structure of the test was as follows. Three starting points of $1, $10, and $50 were employed in the survey instrument. This results in three potential comparisons of starting points for the resulting mean bids: (1) $1 to $10; (2) $1 to $50; and (3) $10 to $50. The null hypothesis was whether the total mean bids were equal within the three combinations of mean bids ignoring all other potential effects. For the $1 to $10 pair, the null hypothesis of no effect was rejected in La Canada and Encino. The $1 to $50 pair was rejected for La Canada and Montebello. Finally, the $10 to $50 pair was rejected only for Redondo Beach.

Another area of consideration is the question of sequencing of information affecting the bid structure not only for the air quality characteristic bids, but also the final bid. The bids were collected according to the following sequences:

1. aesthetic, aesthetic plus acute, and aesthetic plus acute plus chronic, or,

2. acute, acute plus chronic, and acute plus chronic plus aesthetic.

The question of sequencing is whether the ordering of the bidding process effects the size of the component bids. For instance, would individuals bid a different amount for aesthetic effects if it is first, as in (1) above, compared to being last as in (2) above. Similarly, would the acute bids vary? Additionally, we were interested in whether the orderings presented in (1) and (2) would give different total bids. ideally, the sequencing or ordering of bidding information would not affect the results. In an attempt to test for sequencing affects, two separate tests of means were conducted. The first test involved a comparison by area by bid type of the mean values of the observed bids against the derived bids. If an assumption of additivity is made in the bids, then we could obtain an aesthetic observed bid and a derived aesthetic bid. The question is then whether the two bids differ. That is, did the order in which we obtained bids affect the magnitude for the bid. For aesthetic bid, El Monte (A → B), La Canada (A → C), Canoga Park, Encino, Huntington Beach, Irvine, Palos Verdes, and Redondo Beach the null hypothesis was rejected. The null hypothesis was rejected for the acute bids in La Canada, (A → C), Culver City, Encino, Huntington Beach, Newport Beach, and Palos Verdes.

The null hypothesis was rejected for chronic bids for La Canada (A → C) and Newport Beach. Finally, the null hypothesis was rejected for the total mean bids only in Newport Beach and Pacific Palisades. What can be concluded from this set of results? First, the test does not completely resolve the issue of sequencing. In some cases, the mean bids that were observed are statistically different under the assumption of linear additivity. Second, keeping the first point in mind, we note that the total bid does appear to be insensitive to the bidding across different orderings of characteristics of the environmental good air quality.

A second test to further investigate the extent of sequencing effects was to compare each step of the bidding process irrespective of the subject (i.e., acute or aesthetic information) of the bid. The null hypothesis is then to compare the mean values of step 1, the mean differences in values of step 2 from step 1, the mean difference in values from step 2 to step 3, and the total bid. For the first bidding step, only Palos Verdes had the null hypothesis rejected. The null hypothesis for the second bidding step was rejected for Pacific Palisades, Newport Beach and Irvine. For the third bidding step only El Monte was rejected. Finally, the null hypothesis was rejected for Pacific Palisades and Newport Beach. 4 What can we conclude about sequencing from this test? First, again no definitive statement can be made regarding the existence or non-existence of sequencing. However, the results suggest that regardless of the information being bid upon, the step size (i.e., bid difference from the last step) is independent of the information underlying the bid. Second, irrespective of the test the total bid is insensitive to order effects. 5

In conclusion, it was found that the iterative bidding results do not appear to suffer from any systematic biases. Thus, the final section in comparing the results to the property value study will ignore any further consideration of the issue of biases.

Table 1 presents the mean bids by area by type for the 2 year clean-up time horizon. Employing a simple aggregation procedure it was found that 23-50% of the total bids was for aesthetic effects.

Table 1

Mean Bids by Area by Type*

(Completion Date of Cleanup: 2 Yrs.)

Area	Mean Bids ($/Month)			
	Aesthetic Bid	Acute Health Bid	Chronic Health Bid	Total Bid
El Monte (A → B)	1.50 (0.67)** (10)***	6.10 (2.58) (10)	1.20 (0.66) (10)	8.80 (2.99) (10)
El Monte (A → C)	3.61 (6.14) (7)	3.14 (1.40) (7)	3.36 (2.07) (7)	16.11 (8.30) (7)
La Canada (A → B)	9.43 (9.61) (7)	1.29 (0.75) (7)	1.57 (1.41) (7)	12.29 (6.83) (7)
La Canada (A → C)	11.30 (7.48) (10)	5.20 (2.06) (10)	11.00 (5.91) (10)	27.50 (7.50) (10)
Montebello (A → B)	2.56 (1.16) (9)	5.67 (2.92) (9)	1.22 (1.10) (9)	9.44 (4.01) (9)
Montebello (A → C)	19.90 (14.53) (10)	6.18 (2.36) (11)	5.09 (4.51) (11)	29.80 (19.04) (10)
Canoga Park (B → C)	4.50 (2.55) (8)	13.44 (3.87) (8)	3.00 (1.82) (8)	20.94 (5.82) (8)
Culver City (B → C)	5.81 (3.04) (16)	16.81 (6.36) (16)	7.75 (3.35) (16)	30.38 (9.97) (16)
Encino (B → C)	8.41 (2.08) (17)	8.74 (3.37) (17)	1.68 (0.79) (17)	18.82 (3.06) (17)
Huntington Beach (B → C)	9.68 (3.66) (19)	7.10 (1.82) (20)	3.42 (1.36) (19)	20.26 (5.71) (19)
Irvine (B → C)	5.17 (1.50) (15)	13.53 (5.04) (15)	2.87 (1.23) (15)	21.57 (4.79) (15)
Newport Beach (B → C)	3.10 (0.97) (10)	0.70 (0.40) (10)	0.70 (0.48) (10)	4.50 (1.11) (10)
Pacific Palisades (C → C*)	18.00 (11.86) (8)	21.00 (12.46) (8)	8.75 (6.03) (8)	47.75 (29.41) (8)
Palos Verdes (C → C*)	2.41 (1.23) (8)	9.97 (5.89) (8)	1.13 (0.64) (8)	13.50 (5.58) (8)
Redondo Beach (C → C*)	5.29 (2.64) (14)	10.07 (4.17) (14)	2.21 (1.54) (14)	17.57 (6.14) (14)

*The implicit assumption in this table has been that of strict additivity of bids for each air quality effect. In obtaining the mean bids: (1) no differentiation has been made with respect to the bidding sequence; (2) no differentiation has been made whether a health pamphlet has or has not been sent to the respondent in advance of the interview; (3) no differentiation has been made with respect to the different proposed vehicles for the collection of bids; and (4) no differentiation has been made whether a life table has or has not been shown to the respondent during the interview. A life table depicts the "stock" counterparts of the elicited monthly bids for various expected lifespans.

**Standard error of the mean bid in all cases.

***Sample size of each case in all cases.

SECTION 5

THE PROPERTY VALUE STUDY AND EMPIRICAL RESULTS

The purpose of the research on property values was to provide the necessary comparison for the iterative bidding approach which is described above. This was accomplished through an analysis of the housing market within the sample plan communities of the South Coast Air Basin located in Los Angeles and Orange Counties. Specifically, the study asks if households will actually pay for cleaner air in the form of higher property values for homes in clean air communities and if this willingness to pay is comparable to the hypothetical willingness to pay expressed via the survey instrument employed in the iterative bidding procedure.

Valuation of reductions in urban air pollution concentrations based upon housing value differentials is the most common form of the hedonic price procedure as developed by Rosen (1974), the basis of which is Lancaster's (1966) consumption theory. This procedure assumed that access to environmental (dis)amenities is capitalized in property values. This assumption is based on the premise that households are willing to pay for differing levels of air quality.

Previous results indicate that an analysis of the housing market can yield information on the value of non-market goods. However, they also demonstrate the fragility of the methodology.[6]

The approach reported is a refinement on previous work and consists of a multi-step procedure which makes allowance for air pollution abatement to be valued differently by households with varying income levels and initial pollutant concentrations. This methodology was developed recently in a paper by Harrison and Rubinfeld (1978). The first step is to estimate a hedonic housing value equation, which allows for non-linearities where appropriate in the functional form. The second step is to calculate the marginal willingness to pay for individuals in each of the sample communities for a small change in air quality. The third step is to estimate a marginal willingness to pay equation as a function of income and other household variables. The results of this approach will be presented and used to determine benefits of air quality improvements.

A few notes pertaining to the theoretical underpinnings of the analysis are in order. First, the capitalization of environmental goods into housing values can be captured through such empirical work only if certain assumptions concerning the economic behavior of individuals and the functioning of the housing market are accepted. These are: (1) consumers must perceive differences in housing and neighborhood characteristics, expect them to remain unchanged and act on these perceptions; (2) housing markets should function reasonably well and be in short run equilibrium; (3) environmental quality must be exogenously determined and differences in environmental quality be capitalized only in housing prices; and (4) all relevant hedonic price functions should be continuous with continuous derivatives (e.g., there must be sufficient variation in both housing and neighborhood characteristics, including.air quality, to permit continuity. Second, it should be noted that this housing market analysis is consistent with and indeed a substudy within the general theoretical treatment developed in detail above.

The housing characteristic data, obtained from the Market Data Center (a computerized appraisal service centered in Los Angeles), pertains to homes sold in the January, 1977 to March, 1978 time period and contains information on nearly every important structural and/or quality attribute.

Focusing upon the paired communities then, the data base was constructed to enable the impact of air quality differentials on housing sale price to be isolated. Thus, the dependent variable in the analysis is the sale price of owner occupied single family residences. The independent variable set consists of variables which correspond to three levels of aggregation: house, neighborhood, and community. The data base contains 719 independent observations. It should be emphasized that housing data of such quality (e.g., micro level of detail) is rarely available for studies of this nature. Usually outdated data which is overly aggregate (for instance census tract averages) is employed. These data yield functions which are relevant for the "census tract" household and are only marginally relevant at the micro level. However, in this study it was imperative that data comparable to that obtained in the iterative bidding experiment be utilized. That is, since pollution abatement benefit estimates were calculated at the household level in the iterative bidding study, it was necessary to generate similar estimates based on comparable data in this validat ion exercise.

In addition to the immediate characteristics of a home, other variables which significantly affect its sale price are those that reflect the condition of the neighborhood and community in which it is located. That is, the local tax and public goods expenditure rates, school quality, ethnic composition, crime rates, proximity to employment centers (and in the South Coast Air Basin, distance to the beach), and measures of the ambient air quality have a substantial impact on sale price. Therefore, in order to capture these impacts and to isolate the independent influence of air quality, these variables are included in the econometric modeling. The measures of air quality used in the empirical analysis were obtained from California Air Resources Board publications (1977). In conclusion, the data base assembled for the housing value study appears appropriate for comparability testing of the iterative bidding experiment. The reasons are three fold. First, the housing characteristic data is extremely detailed; at the household level of aggregation; and extensive in that a relatively large number of observations are considered. Second, we have assembled a variety of neighborhood and community variables which enable the isolation of the air quality influence on housing values. Third, the air pollution data is comprehensive.

The results of the hedonic housing value equation estimation are presented in Table 2. As measured by R^2, the non-linear functional form performs somewhat better than a linear equation. In the NO_2 equation all independent variables conform to our a priori expectations concerning the relationship to sale price and all except ethnic composition are statistically significant at the 5% level ($|t| \geq 1.645$). A similar statement holds for the TSP equation except that crime replaces ethnic composition as the only insignificant variable. In their respective equations, the air pollution variables are highly significant. Note also that squared pollution terms were utilized in the estimation. It was found that these performed better than either the first-order or cubic terms. However, the performance difference was not significant. Therefore, further analysis (benefit calculations, etc.) based on the equations containing the first or third order terms was completed and is discussed below.

The non-linear specification prevents straightforward analysis of the quantitative impact of a unit change in an independent variable since the effect depends upon the level of all other variables. However, if NO_2 and the other variables are assigned these mean values then a unit improvement in NO_2 (one PPHM) is valued at $2,010.

Before proceeding to the next procedural step, a few comments concerning the effect of misspecification bias are in order. That is, we conducted experiments to see what would happen to the coefficient on air pollution if certain neighborhood variables were omitted from the equation. For example, if distance to beach is excluded then the air pollution coefficient increases from .0010374 to .0034176. Similarly, if population density is omitted then the pollution coefficient increased to .0024284. In each of these cases the air pollution term serves as a measure of pollution and other neighborhood disamenities as well. These specification errors would eventually result in biased benefit estimates. Therefore, a fully specified equation is crucial.

The estimated equations shown in Table 3 yield the marginal willingness to pay for improvements in air quality by taking the derivative with respect to the relevant air pollution variable. This procedure supplies information on the amount of money the average household in each community would be willing to pay for small changes in pollution levels. This information, in conjunction with community average income and pollution levels, are the basic inputs to the third methodology step - estimation of the willingness to pay equation. Table 3 presents two formulations of this equation for NO_2. The first assumes a linear relationship while the second postulates a log-log form. As is indicated by the coefficients both income and pollution are positively related to marginal willingness to pay. Thus, higher income communities in poor air quality regions have the greatest willingness to pay. Similar results were discovered for the TSP based equations but are not presented.

Given this analysis it then becomes possible to complete the multi-step procedure and calculate: (1) the average sale price differential attributable to changes in air quality; and (2) benefits derivable from these changes in per home, per day units. The first calculation is accomplished by integrating the willingness to pay equations (assigning the income variable its mean value) over the range of air quality improvement.[7] In this manner, the reduction in pollution consistent with the poor to fair improvement is valued at $5,793/home for the linear NO_2 willingness to pay equation and $6,134/home for the log-log

Table 2

Estimated Econometric Equations

Dependent Variable = Log (Home Sale Price in $1,000)

Independent Variable	NO_2 Equation	TSP Equation
Sale Date	.018439 (10.108)	.018924 (10.427)
Age	-.0027044 (-3.5185)	-.0031401 (-4.1178)
Living Area	.00019976 (14.024)	.00019688 (13.896)
Bathrooms	.14777 (9.2661)	.15285 (9.6443)
Pool	.089959 (4.2096)	.092764 (4.389)
Fireplaces	.10355 (7.8325)	.099225 (7.5833)
Distance to Beach	-.014037 (-9.1443)	-.013132 (-9.1824)
Distance to Employment	-.26979 (-11.663)	-.23201 (-9.1314)
Crime	-2.2798 (-2.3574)	-1.5245 (-1.5444)
School Quality	.00099327 (2.0286)	.0010087 (2.0792)
Ethnic Composition	.0081532 (1.2523)	.027307 (4.5564)
Population Density	-.000067145 (-7.8422)	-.000061627 (-7.2705)
Log (Tax)	-.030991 (-1.8253)	-.046438 (-2.7565)
Public Safety Expenditures	.00032792 (5.1487)	.00028288 (4.8582)
$(TSP)^2$	-	-.000015702 (-4.1798)
$(NO_2)^2$	-.0010374 (-2.6935)	-
Constant	4.2297 (6.2304)	2.3602 (3.8836)
R^2	.877	.878
Sum of Squared Residuals	22.62	22.29
Degrees of Freedom	703	703

Table 3

Estimated Willingness to Pay Equations (NO_2)*

Dependent Variable = Marginal Willingness to Pay in Dollars

Independent Variable	Coefficient	t-statistic
Constant	-1601.3	-2.7622
Income**	.050051	8.2662
NO_2 level	162.67	3.7832

R^2 = .864
Degrees of Freedom = 11

Dependent Variable = Log (Marginal Willingness to Pay in Dollars)

Independent Variable	Coefficient	t-statistic
Constant	-6.4845	-5.7025
Log (Income**)	1.1473	13.092
Log (NO_2)	.87283	6.1051

R^2 = .942
Degrees of Freedom = 11

*These equations are based on the hedonic housing value equation which utilizes $(NO_2)^2$ as the air pollution measure.

**The income variable is defined as average community income and in dollars.

NO_2 equation. The values which correspond to the fair-good change are $4,244/home and $4,468/home, respectively. If TSP is used as the measurement criteria then poor-fair is valued at $6,053/home (linear) and $6,033/home (log-log) while fair-good is valued at $5,677/home (linear) and $5,964/home (log-log).

The above figures are translated into average benefits illustrated in Table 4. As can be seen from examination of Table 4 daily household benefits calculated using the multi-step procedure range from $1.40/day/home to $1.48/day/home or $42.00 and $44.40 per month, respectively for NO_2. These are considered our "best" estimates since the technique used in their specification at least addresses known methodological problems.

Further, the TSP based calculations remain fairly constant at about $1.60/day/home, so the daily household willingness to pay to achieve the specified air quality improvements are relatively insensitive to the pollutant used in the willingness to pay equation. The TSP results are also insensitive to the specification of the hedonic housing equation, the first link in this methodology. That is, whether the first or third order TSP term was used in this equation (rather than the squared term) had little effect on the eventual benefit calculations. However, this was not the case for NO_2. In this instance, daily household benefits fluctuated from a low of $.87/day/home or $26.10 per month [$(NO_2)^3$ used in hedonic housing equation and linear willingness to pay equation] to a high of $2.09/day/home or $62.70 per month [first order NO_2 term used in housing equation and linear willingness to pay equation].

In conclusion, we have attempted to describe and utilize a multi-step approach to the determination of air pollution abatement benefits. Each of the steps is linked to those that preceed it. Therefore, benefit calculations are a function of a hedonic housing value equation, the resulting marginal willingness to pay data, and an estimated willingness to pay schedule which yields the sale price differential attributable to air quality. Finally, our "best" estimates of daily household benefits was $1.40/day/home calculated using the second order NO_2 term in the hedonic housing equation and a linear willingness to pay equation. However, benefits could easily range from $.87/day/home to $2,09/day/home.

Table 4

Benefits - Multi-Step Econometric Methodology*

(A) NO_2 (TSP) - Linear Willingness to Pay Equation

Change in Air Quality	Capitalized Benefits (Billion Dollars)	Annualized Benefits (Billion Dollars) R = .0925, CRF = .0995
Poor to Fair	6.12 (6.4)	.61 (.637)
Fair to Poor	3.42 (4.6)	.34 (.458)
Total	9.56 (11.0)	.95 (1.095)

	Capitalized Benefits ($)	Annualized Benefits ($) R = .0925, CRF = .0995
Per Home	5136 (5910)	511 (588)
Per Home Per Day		1.40 (1.62)
Per Home Per Month		42.00 (48.30)

(B) NO_2 (TSP) - Log-Log Willingness to Pay Equation

Change In Air Quality	Capitalized Benefits (Billion Dollars)	Annualized Benefits (Billion Dollars) R = .0925, CRF = .0995
Poor to Fair	6.5 (6.4)	.645 (.64)
Fair to Poor	3.6 (4.7)	.355 (.47)
Total	10.1 (11.1)	1.0 (1.1)

	Capitalized Benefits ($)	Annualized Benefits ($) R = .0925, CRF = .0995
Per Home	5427 (5964)	540 (593)
Per Home Per Day		1.48 (1.63)
Per Home Per Month		44.40 (48.90)

*Note that in the estimated hedonic housing equation (step 1) the second order pollution terms were used.

SECTION 6

PRELIMINARY COMPARISONS BETWEEN PROPERTY VALUES AND ITERATIVE BIDDING RESULTS

The South Coast Air Basin Experiment consisted of an attempt to value air quality through examination of differences in property values and through an interview survey instrument to measure willingness to pay. Six pairs of neighboorhoods were selected for comparative purposes. The pairings were made on the basis of similarities of housing characteristics, socioeconomic factors, distance to beach and services, average temperatures, and subjective indicators of the "quality" of housing. Thus, for each of the pairs, an attempt was made to exclude effects on property values other than differences in air quality.

While the sample paired methodology was an attempt to establish comparability between results of the research designs, certain cautions should be kept in mind. These additional assumptions are that:

1. an implicit hypothesis exists such that there is a directional consistency between the types of biases of the two research designs;

2. in a theoretical sense, each research design is measuring the same "good;"

3. the groups being sampled are identical within the paired areas;

4. the time frames from which the valuation estimates are derived are assumed constant (i.e., equilibrium versus non-equilibrium contexts for individuals and markets); and

5. a problem exists in assigning proper weighting for a set of diverse samples.

With these difficult qualifications in mind, let us turn to a preliminary comparison of results obtained from the property value and sample survey results. Table 5 provides some <u>extremely</u> preliminary results on monthly valuations by households of an arbitrary improvement in air quality in the Los Angeles Basin of approximately 30%. For the paired comparisons property value study, the estimate per household with no adjustments for household differences except in a real and subjective sense is approximately $135 per month. Extrapolated to the basin as a whole yields an annual benefit from improved air quality of 30% of approximately $4 billion.

The other extreme is an estimate of improved air quality per month by household utilizing results from the survey which are highly preliminary, of approximately $26 per month per household. This yields a rough estimate of

The results compiled in this study suggest that survey instruments, when compared to property value techniques, provide a reasonable mechanism to obtain environmental quality benefit estimates. The survey approach has the advantages that: (1) data can be collected at low cost on specific environmental problems (the investigator is not tied to the availability of existing data sets); (2) beneift measures can be disaggregated across individuals and sources of benefits from various characteristics such as asthetic experiences and preceived health can be obtained; and (3) a voluntary consumer statement of willingness to pay gives some justification in and of itself for expenditures on air quality and perhaps more generally on environmental quality programs.

Table 5

Alternative Estimates of Monthly Bids by Household
Total Benefits for Air Quality Improvement
in the South Coast Air Basin

(Approximate 30% Improvement in Ambient Air Quality)

	Property Value Study			Survey Study	
	Paired Communities	Linear Regression	Non-Linear 3-Step	Mean Bid	Regression Results
Average ($) bid per house hold per month	$135	$51-115	$42*	$29**	$26***

*Best estimate, possible range, $26-63 per month.

**Based on maximum total bid with an adjustment for years to achieve improvements in air quality.

***Based on maximum total bit equation with an adjustment for the amount of air pollution information available to the household.

FOOTNOTES

1 Distributional effects are ignored at this point.

2 See Brookshire, Randall and Stall (forthcoming) for a complete discussion of contingent markets, used in the iterative bidding approach.

3 Props are an integral part of establishing the hypothetical market and existing situations. For instance, individuals were shown an 8" x 10" map depicting the South Coast Air Basin in terms of ralative levels of air quality - good, fair and bad.

4 This is the identical result noted in the first sequencing test which by the structure of the tests must be the same.

5 A follow-up on this thesis would be a test of the total step size 1 against total for step 2 against total for step 3.

6 See Ridker and Henning (1967), Anderson and Crocker (1971), Deyak and Smith (1978), Steele (1972), and Wieand (1973). The fragility of the method is demonstrated when comparing Wieand (1973) and Ridker and Henning (1967) since Wieand employed essentially the same data base as Ridker-Henning but derived quite different resutls. The major change being monthly rent per acre in place of median property value as the dependent variable.

7 The formula used in these calculations is

$$\int_{\text{Pollution after}}^{\text{Pollution before}} (WTP_i)\, d\ \text{Pollution}$$

where WTP_i = f (income, pollution).

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BENEFITS STUDY ON CORROSIVE WATER

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INTRODUCTION

In fulfilling its mandate, the U.S. Environmental Protection Agency, promulgates regulations controlling the release of pollutants by firms and individuals. Because compliance with these regulations often calls for large expenditures, EPA and the public frequently scrutinize these costs.

For a variety of reasons--including the difficulties of obtaining needed scientific and economic data and the agency's broad mandates from Congress--the benefit side of a benefit/cost assessment is rarely conducted. Without benefit analysis, however, cost analysis is not particularly illuminating in the decision-making process. To base decisions solely on technical feasibility and estimates of compliance costs potentially wastes valuable resources that could be directed to more productive uses.

This paper reports the results of an attempt to evaluate both the benefits and costs of a proposal to control the corrosivity of public water supplies. While benefit analysis has many serious methodological and data problems, this study illustrates that even highly incomplete information on benefits can be extremely useful to decision makers. Society can avoid the potentially significant waste of resources that may result from analyzing cost and technical feasibility only.

EPA is concerned about corrosive water because it can leach potentially harmful substances such as lead and cadmium from the pipelines, and it may be a cause of cardiovascular disease. Corrosive water can also accelerate the deterioration of water providing a ready supply of lead leachate. While 90-95 percent of the lead ingested is passed through the body, in sufficient quantities, lead poisoning can be a problem. Even trace amounts can be harmful. The effects of lead poisoning are well documented. Lead enters the blood and is absorbed into the tissues. If it reaches the brain, it tends to accumulate, according to Dr. Ellen Silbergeld of the National Institute of Neurological and Communicative Disorders and Stroke.(3) Lowered sperm counts have been documented.(7) In addition, lead poisoning causes anemia and encephalopathy. Initial symptoms of encephalopathy include dullness, restlessness, irritability, poor attention span, headaches, muscular tremors, hallucination, and the loss of memory. Eventually the poisoning may cause delirium, mania, convulsions, paralysis, coma and even death. All of these symptoms are associated with damage to the central nervous system.

Children and pregnant women are thought to be the populations at greatest risk from lead exposure and most cases do involve children. Proportionally, children retain more lead than adults, making them vulnerable to poisoning at lower levels. Elevated blood lead levels in pregnant women may damage the brain of the fetus, and result in mental retardation. Correlation between drinking water lead levels and mental retardation has been shown in several studies. Experiments conducted by Richard Bull of EPA's Health Environmental Research Laboratory (HERL) with rats have shown that lead exposure in the post-natal period is not as significant as prenatal, further underscoring the risk faced by pregnant women.(4) Other studies show that the effects of poisoning and encephalopathy can be permanent. Permanent damage to child-

Another approach to measuring corrosivity is to use coupons inserted into the distribution system for a period of time. A coupon is merely a rectangular piece of metal, usually the same material as the pipeline. While this method certainly gives an idea of how the material reacts with the water, it does not accurately reflect the conditions the pipes face. The coupon is suspended in the middle, where many characteristics of the water are different (especially rate of flow) from those of the water along the side.

The only method for accurately measuring corrosion is to actually remove sections of the pipe periodically and examine them. While this approach is costly for new pipes or a new system, eventually pipe replacement will be necessary so that pipe removal occurs anyway.

Because of the uncertainty involved in explicitly measuring corrosion, any future EPA regulations will not set an MCL. Instead, they would take the form of requiring testing by the Langelier Saturation Index and if corrosivity is indicated, treatment may be implemented.

HEALTH EFFECTS

EPA's primary concern is the prevention of health problems arising from poor quality drinking water. The effects of the three contaminants of greatest concern are examined along with possible problems from soft water.

Lead

The most common source of lead poisoning is lead paint, though drinking water could conceivably also be a source. Many older buildings still use lead pipes and all solder contains lead,

<u>Total Dissolved Solids</u> - high concentrations increase conductivity and may increase corrosiveness

<u>High Temperature</u> - usually accelerates corrosion

Adding chemicals to adjust these factors can slow the corrosion rate and reduce the danger of exceeding the MCLs.

While the effects of internal corrosion on pipes are quite visible after the fact, determining if the water will be corrosive in advance is difficult. No good measure exists, and the indices currently in use can only indicate corrosion potential at best. Corrosivity depends on many factors, and the interactions between them are poorly understood. As corrosive water is usually soft water, the latter is sometimes measured instead. Some of the indices currently in use include:

<u>Langelier Saturation Index</u>: (LSI) This is the oldest index and several variations exist. It's an expression of the tendency to form or dissolve calcium carbonate scales. Negative values indicate corrosive water and are calculated by $I = pH - pH_s$ where pH is the measured pH and pH_s is the saturation pH.

<u>Ryznar Index</u>: It also indicates the relative scale-forming or aggressive tendencies of the water. Deposition decreases as the index rises above 6, and the water is considered extremely aggressive with values of 10 or above. In this case $I = 2pH_s - pH$.

<u>Halogen-Alkalinity Ratio</u>: Dr. T.E. Larson's work seems to have shown a relation between the proportion of chloride to bicarbonate alkalinity as determined on a molar basis. Increasing corrosiveness is associated with ratios exceeding 0.5 for source waters.

<u>Aggressiveness Index</u>: Developed for use only with asbestos/cement pipes, this simplified version of the LSI is concerned with the amount of asbestos fibers leached. If AI<10 the water is highly corrosive: if 10-AI-12, it is moderately corrosive; and the water is not corrosive if AI>12. The formula is:

$I = pH + \log(AH)$ where
A= alkalinity in mg/liter as $CaCO_3$ and
H= calcium hardness in mg/liter as $CaCO_3$.

systems resulting in increased operation and maintenance expenses for the water supply system. Corrosion can be controlled by various treatment techniques before entry into the distribution system. To examine the specifics of these effects requires first some understanding of EPA's mandate and the chemistry of corrosive water.

BACKGROUND

Under the mandate of the Safe Drinking Water Act, Public Law 92-523, the Environmental Protection Agency established the National Interim Primary Drinking Water Regulations. These regulations set maximum contaminant levels (MCL) for various types of contaminants in drinking water and required them to be met at the consumer's tap--a significant departure from previous regulations which required the MCLS to be met at the treatment facility. The National Secondary Drinking Water Regulations expands on those regulations by suggesting limits for iron, copper, and zinc. If the water is corrosive, additional contaminats will be picked up between treatment at the distribution point and the tap. Reducing corrosion will help meet the MCLS at the tap.

Some of the conditions that contribute to corrosivity in water and their effects include:

Low pH - generally accelerates corrosion, especially of ferrous materials

Low Buffering Capacity - insufficient alkalinity to provide protective films

Dissolved Oxygen - induces corrosion, especially of ferrous materials

High Halogen and Sulfate/Alkalinity Ratio - ratio above 0.5 results in conditions which favor pitting ren may even occur with only mildly elevated levels.(8) The permanency of the damage seems to be the biggest danger. As Dr. Silbergeld states, although lead exposure does not produce people who cannot function, it may be reducing their potential.

The benefits of preventing lead poisoning are obvious. However, uncertainty exists regarding the extent drinking water is responsible for total lead intake. A MITRE report estimates that lead from drinking water represents 6-70 percent of the total intake for pregnant women, a rather wide range. The same report indicates that drinking water is responsible for 1-69 percent of lead ingested by children with pica, (i.e., who eat non-food items such as paint and dirt) and 2-74 percent if they don't have pica. A World Health Organization report states that exposure through water is generally lower than that through air and food. Lee McCabe (HERL, EPA) claims that drinking water accounts for 5-10 percent of all lead consumed. Of course, these figures will vary according to the degree of corrosivity and whether or not the water passes through lead pipes.

The question, then, is whether lead levels in drinking water are high enough to be of concern. McCabe's 1974 Community Water Supply Study (CWSS) found that 1.4 percent of the systems exceeded the MCL of 0.05 mg/l. Another study, by Scholefield, found that 2.5 percent of the sample exceeded the MCL.(17) This second study used tap samples collected by Culligan Company, a distributor of home water softeners. The sample could be somewhat biased as it probably does not include data from older, dilapidated housing that is more likely to have lead pipes but less likely to have residents who can afford water softeners. The highest lead level found was 0.5 mg/l which will add between .03-.09 mg/100ml of lead to the blood.(25) Lead poisoning is generally considered to occur if the blood lead is greater than 0.05 mg/100 ml. Subclinical effects can occur at much lower levels. For children, the danger level is thought to be .03 mg/100 ml, which will add .003-.009 mg/100 ml to to the blood.(19) While 0.05 mg/l is the MCL, the National Academy of Science recommends 0.025 mg/l which will add .0015-.0045 mg/100 ml to the blood lead level.

Nationally, according to Scholefield, 8.6 percent of the water exceeds the recommended level. These numbers imply a significant number of people are drinking water with excessive lead levels. Some 180 million people get their water from community supplies. McCabe's results imply a lower bound on the number of people affected is 1.4 percent of 180 million or 2.5 million and an upper bound is 8.6 percent of 180 million or 15.5 million, from Scholefield. The true number is probably somewhere in between. The areas with excessive levels do correspond to areas with corrosive water according to Scholefield.

The high lead levels can be reduced through corrosion control. Peter Karalekis of EPA's Region I cites a small sampling of houses in Cambridge with lead pipes and corrosive water. Of the houses sampled, 7.8 percent exceeded the MCL of 0.05 mg/l of lead. After treatment, every house in the sample had less than 0.02 mg/l of lead, which is significantly less than the MCL.

A potential problem certainly exists. If high blood lead levels are found, the cause may well be the water. Yet, even in areas where extraordinarily high levels of contamination occurred, water actually consumed from the tap may be quite different from the samples collected at the treatment plant. Similarly, because people move about, current exposure could be poorly correlated with lifetime exposure. Furthermore, many variables other than water quality --such as bad dietary habits and smoking-- are known to affect CVD. Only when the analysis includes these variables, can one be reasonably certain that the measured correlations are not spurious.

A detailed study of individuals would avoid these problems. One such study is currently under way, sponsored by EPA and the National Institutes of Health (NIH). British scientists have also been very active in this area and so far their results support the thesis. The completion of the EPA-NIH study, which appears to be well designed and executed, should provide some more definitive answers about the relationship between CVD and corrosive water.

One hypothesis based on the absence of magnesium explains the mechanism behind any link between CVD and soft water. Work in England and Canada shows low magnesium levels in the tissues of people who died from heart attacks. Similar differences have been found in tissues of residents of hard and soft water areas.(7) As magnesium is a major contributor to hardness, the explanation is reasonable.

BENEFITS OF CONTROLLING CORROSIVITY IN WATER HEALTH BENEFITS

Health Benefits

Deriving estimates of the reduction in deaths from cardiovascular disease that would result from changes in the hardness

Cardiovascular Disease

In 1957, Kobayashi, working in Japan, noticed a positive correlation between cardiovascular disease (CVD) and soft water. As corrosive water is also usually soft water, this possible relationship needs to be examined when considering the benefits of regulations. Although many different studies have investigated this relationship, most were poorly designed. The results are conflicting and seem to depend in part on the geographic units under consideration.

In 1979, Dr. George Comstock of Johns Hopkins University reviewed the literature on the relationship between CVD and soft water. The studies that involve large geographic areas--states or countries--tend to support the association between water hardness and CVD. These are also the more prevalent types of study. Two studies of areas within cities or counties, fail to support Kobayashi's findings. When cities were compared, two of.eleven studies support the thesis while six are inconclusive. The correlation between water softness and CVD is apparently observed only in large geographical areas.

No completely satisfactory explanation for this phenomonen has been advanced. It is possible that no matter how accurate the data or sophisticated the model, problems exist with the kinds of analysis that have been discussed so far. For example, very few of the studies sampled water at the consumer's tap. Additional minerals can be leached from the household plumbing or home water softeners may have been installed. Thus, the occurs in abnormally high concentrations in hypertensive people. Cadmium accumulates in different tissues, but especially in the kidney. It also interferes with two normal, beneficial processes, zinc binding and calcium metabolism.(8) If the CWSS is a representative sample, this problem is not very prevalent, affecting only about 360,000 people.

Asbestos

The third possible problem from corrosive water has arisen with the use of asbestos/cement (A/C) pipes because water distributed through these pipes contains asbestos fiber. Although asbestos fiber has proven to be a carcinogen when inhaled, it is only suspected of causing cancer when ingested. According to Richard Woodhall of the Connecticut Department of Health, adverse health effects have not yet been observed from A/C pipes. However, studies are continuing because researchers expect such an effect does exist.

In U.S. v. Reserve Mining Co., the judge ruled that the company must stop disposal of its effluent into Lake Superior because the effluent contained taconite tailings with fibers identical or similar to amosite asbestos. The judge considered the existing evidence on the correlation between cancer and taconite sufficient to order the disposal stopped. In the meantime though, it is impossible to predict whether asbestos-related benefits will accrue from the regulation.

the population was largely unaffected. Bennington, Vermont, discovered in May 1977 that drinking water lead levels reached 0.41 mg/l in some cases, with the mean being 0.04 mg/l. Children were then tested to determine adverse health effects. Ten children were identified as victims, but none of them lived in homes with high lead concentrations. A similar result was obtained in Glasgow, Scotland, where some houses have lead-lined storage tanks, lead pipes, and lead levels up to 8 mg/l. Not one person's blood lead exceeded .04 mg/100 ml. A small number of clinical abnormalities was found, but they could not be directly attributed to lead toxicity.(g) These two examples make it difficult to say that lead contamination from drinking water is a problem by itself. However, for someone exposed to lead from other sources, the additional increment from water could be the difference between safety and danger. The threshold for bioaccumulation of lead ranges from .1-.3 mg/day for children. Thus, even if a child consumed .2 mg/day from food, two liters of water with 0.05 mg/l of lead would be required for the threshold to be exceeded in the absence of exposure to non-food lead sources. This observation suggests children in urban areas are at greater risk from water lead.

Cadmium

Water can also leach cadmium. McCabe's CWSS showed that 0.2 percent of the systems sampled exceeded the 0.01 mg/l MCL. Cadmium may be a cause of cardiovascular disease. Experiments have shown that it induces hypertension in animals and it also of drinking water is difficult. Because of the problems with most of the studies mentioned earlier, none of the figures can be interpreted as definitive. Energy and Environmental Analysis, Inc., reviewed the problem recently, concluding that for each ppm of hardness added, 0.63 deaths per 100,000 exposed population could be expected to be avoided each year. Comstock who develops risk reduction estimates, took a different approach. Using studies that included data on the water hardness, he estimated the risk for someone drinking extremely soft water, (0 ppm of hardness) as being only 15 percent greater than someone drinking extremely hard water, 200 ppm hardness. Water is considered soft if it is less than 60 ppm and EEA says most treated water is hardened to about 100 ppm. Assuming linearity in risk with respect to hardness, the greatest reduction in risk possible will then be half of 15 percent, or 7.5 percent, and for most people it will be less. The 1976 United States Statistical Abstract reports 383.5 deaths per 100,000 people from CVD in 1976. EEA estimated that 55.3 million people drink soft water. Thus, in this group, one would expect up to an extra 29 deaths per 100,000 people. A maximum of 16,000 deaths per year might be avoided if the risk is completely removed.

Operations and Maintenance Benefits

Corrosive water has other effects not related to health. The process of leaching minerals causes excess interior degradation of the pipes, making them more susceptible to leakage and rupture. In addition, tuberculation may occur. The tubercules roughen the interior of pipes and create resistance to the flow of water by reducing the diameter. Higher water pressure is then required to prevent loss of carrying capacity, necessitating additional energy use and increased expenditures.

Treating corrosion will lessen these effects. The problem is determining how much is preventable, since breaks will still occur as the pipes are subject to such strains as overhead traffic, construction work, and earthquakes. Delaying the first break is important. Research by Robert Clark (MERL, EPA) shows that probability of a break occuring follows an exponential distribution. Thus, once a break has occurred, the probability of another is much higher.

Other Benefits

The leaching of minerals can cause discolored water and can stain porcelain fixtures. Both of these effects are frequent sources of consumer complaints. Increasing the hardness of water eliminates these problems. The rise in complaints from disgruntled consumers has contributed to the improvement of the water systems in some cities. After Seattle introduce a new water source, the objections from consumers the city to study its problem. Norwalk, Connecticut, also began a program of chemical additions when customer complaints increased. The results in Norwalk are quite satisfactory: complaints have been eliminated and the corrosion rate--as measured by coupons--has been cut on average 16 mils per month during the summer, or approximately 36 percent. Virtually no corrosion occurs in the winter because of the lower temperatures.

Treatment costs vary with the characteristics of the water and the size of the treatment facility. No uniform treatment method exists, but all methods seem to benefit from economies of scale. Some methods involve adjusting pH or alkalinity while others add lime, silicates, or phosphates to create a protective coating along the walls. The most common method is to maintain calcium carbonate stability, usually by the addition of lime. Health officials and EPA discourage the use of additives containing sodium because of concern about the relationship between sodium and heart disease. However, sometimes water characteristics require their use. None of the other methods have had any detrimental health effects associated with them. Thus, the only costs associated with treatment are the actual expenditures for labor and any necessary materials such as chemicals.

EPA has estimated the annual cost of treatment with lime for various size plants. The costs in Table 1 range from $16.40 per person for an extremely small plant to $0.25 per person for a plant with a capacity of 100 million gallons per day.

Table 1

Cost of Using Lime to Treat Corrosivity

Plant Size (gallons/day)	$/1,000 gallons treated (70% of Capacity)	$/Capita
2,500	0.455	16.40
50,000	0.137	5.00
5,000,000	0.022	0.80
100,000,000	0.007	0.25

The equation used in deriving Table 1 was developed by Dr. Robert Clark (EPA-MERL) from data collected by Gummerman, Culp, Aggregating the cost nationally may not be the best way to understand the magnitude of the impact of corrosive water. An alternative approach is to analyze one particular distribution system, as Kennedy Engineers did in Seattle. Their work showed that corrosive water especially deteriorates galvanized steel pipes. Copper pipes also become pitted and tuberculated but not as extensively. And, though the city does not have any asbestos/cement pipe, some residences do and may be harmed by the asbestos. All told, the cost estimate per capita from corrosion is about $2.21, which is in line with EEA's estimates. Although these figures include only utility-owned distribution sytems, treatment will also benefit privately-owned systems and building plumbing. Therefore, they are underestimated.

The magnitude of the problem is illustrated by a utility in Dade County, Florida, that ended its treatment program in an effort to cut costs. Breakages increased so much that the move actually cost more money than treatment. Today, the utility is once again treating its water.

Compliance with such a regulation would entail additional expenditures that need to be subtracted from the savings to determine the benefits. The proposed regulation will require surface water to be tested twice a year and groundwater at least once a year. The Langelier Saturation Index test will cost about $20, while the Aggressiveness Index is even less expensive. EPA estima- already required to provide data on other characteristics. Reporting one more will not measurably increase the time or effort needed.

costs of corrosion. Because response rates for utilities serving fewer than 50,000 people were very poor, their results exclude that category. The self-reported costs totalled $8.299 million annually, but this drops to $3.019 million if the largest estimate is removed. The corresponding per capita costs are given as $1.15 and $0.42. Either the omitted utility's problems are much more severe than those others face, or it interpreted the question quite differently.

The MRI report then computed a cost/benefit ratio. The report counted all the additional operation and maintenance costs from corrosion as the potential benefits to be derived from treatment, ignoring the fact that some corrosion is unavoidable. Thus, if the report's figures are accurate, the benefits are actually lower.*

Using more careful analysis, Energy and Environmental Analysis, Inc. (EEA), showed the annual cost per capita as $2.67. EEA assumed that operating costs of pumping facilities are proportional to total flow, and that repair costs are proportional to pipe length. Some of its work was based on an analysis Kennedy Engineers did for the city of Seattle, Washington, that showed that corrosion rates can be reduced by 30-75 percent.

In an attempt to estimate the damage caused by corrosive water, Hudson and Gilcreas claim that distribution capacity is reduced by one percent per year normally, and corrosive water doubles that rate. The total annual loss is $375 million or $2.08 per capita. However, they offer no explanation of their methodology.

*The validity of MRI's numbers are questioned when a little arithmetic shows that the one aberrant utility serves only 28,418 people and should have been excluded altogether.

NEGATIVE EFFECTS OF CORROSION CONTROL

Hardening the water has one known negative impact. It impairs to various degrees the cleaning and sudsing actions of soaps and detergents with the effectiveness of laundry and automatic dishwasher detergents being the most impaired. However, a rule of thumb in the industry is that most detergents are still adequate in water with moderate hardness--up to about 120 ppm as $CaCO_3$--and won't require additional amounts of water softeners.(4) Since most water isn't hardened past 100 ppm as $CaCO_3$, consumers will not be incurring additional costs.

It is also possible that the treatment methods could themselves cause health effects. Some objection has arisen to adding sodium to the water--which some methods require--as sodium may be correlated with heart disease. However, the concentrations involved are so low that any additional risk is negligible. No other methods for reducing corrosivity seem to have any adverse effects.

MONETIZATION OF BENEFITS

An effort will now be made to quantify the benefits from regulation. The potential health benefits arise from reducing the levels of contaminants and the problems they may cause otherwise, along with the decrease in cardiovascular disease. But the easiest benefit to quantify is the savings from lowered operations and maintenance expenditures. Several attempts have been made to determine these savings.

The Midwest Research Institute (MRI) mailed surveys to water utilities across the country that asked about the annual and Hansen. Using this equation and information from MRI about the utilities reporting corrosive water, the average national cost per person per year is $0.86. This figure is probably somewhat low because of the exclusion of small utilities and because lime is one of the cheaper treatment methods. Also, these figures assume that only one plant serves all the customers and that is not always the case. As a result, the economies of scale will not be as great as supposed.

The question arises of how large the affected population is. Surveys have shown that sixty percent of the nation's water is corrosive to some degree. Sixty percent of the 180 million people served by public water systems implies that 108 million people are affected but EEA has estimated that only 55 million people drink corrosive water.

Recalling that the estimated benefits arising from expenses avoided range from an average of $2.08 to $2.67 per capita per year which are greater than $0.86, the regulation is apparently justified. A look though, at Table 1 shows that this is not true for small systems. However, the potential reductions in health risks may still justify the expenditures.

Because more research has been done on the value of a life than on the other health benefits, the next easiest item to quantify is the value of lives saved from a lower CVD rate. The ethical foundations of doing so are always subject to attack, but the fact remains that we all implicitly make decisions every day about how we value our own lives. We decide to buckle the seatbelt, drive slowly, or to take a low-pay, low-risk job, revealing in the process what we are willing to pay to avoid harm, which is a much more accurate approach than merely asking what a benefit is worth.

Blomquist and the team of Thaler and Rosen tried to ascertain how much a person's life is worth by looking at these implicit decisions. The former used wage differentials and the latter looked at data on the use of seat belts. Martin Bailey reviewed these studies, adjusting the estimates to 1978 dollars and including third-party costs borne by the family and friends. Table 2 details the ranges of the adjusted estimates.

Table 2

Value of Life

	Thaler and Rosen (In 1976 dollars)	Blomquist
Low	170,000	256,000
Intermediate	303,000	409,000
High	584,000	715,000

From the data on CVD rates and on the reduction of risk from CVD caused by water softeness, one can calculate the implicit values of life as shown in Table 3. Although they should be calculated with the savings from system maintenance netted out, only average figures are available. Thus, the amount spent for each life is actually overestimated. Comparing the two tables, it is clear that the amount to be spent for all systems is well within the amount considered reasonable. The regulation then, is justified for small systems too. More importantly for EPA, which is concerned only about health effects, the expense is

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euthanasia make clear. These problems, along with the strains placed on existing statistical and epidemiological techniques illustrate where future research needs to be focused.

treatment would pass a benefit/cost test. These results are not necessarily true for the smaller systems until the decreased incidence of CVD is taken into account. Table 4 summarizes all the quantitative information. The numbers are reasonable and show that consideration and monetization of benefits can be meaningful in an environmental context.

TABLE 4

Summary of Results

Benefits/Problems	Number of People Affected	Savings (+) Costs (-)
Lead Poisoning	0-15,500,000	+
Cadmium Poisoning	3600	+
Asbestos	?	+ (?)
CVD mortality	0 - 16,000	+$200,000 to +$600,000/lif
CVD moridity	?	?
System maintenance	0-108,000,000	+$2.08 to +2.67/capita
Testing	180,000,000	-$20/yr./system
Treatment	0-108,000,000	-$0.86/capita on average -$0.25 to -$16.40/capita

This work also illustrates the problems such an analysis faces. Choices have to be made in spite of much uncertainty, and a wrong decision could lead to many avoidable deaths. Where the range of risks faced is the same for everyone, one can compare decisions about facing similar risks. But, it is harder to compare when the ultimate result may be illness. Obviously, the flu for a few days is preferable to death. With a chronic, debilitating, or painful disease, the preference may well be for death, as the advocates of well worth it for all systems even without including operation and maintenance benefits.

Table 3

Value of Life Necessary to Justify Treatment

Plant Size	$/Capita	Lives Saved	Value of Life
2500	16.40	.007	57,000
50,000	5.00	.144	17,000
5,000,000	0.80	14.381	2,000
100,000,000	0.25	287.625	870

Quantifying the benefits from reducing the levels of contaminants is more difficult. Not as much is known about the effects of cadmium and asbestos as is known about lead. The effects of lead poisoning are well documented but it is unclear how the cost of minimal brain damage or hyperactivity should be determined. We have already shown that the benefit/cost ratio is greater than one so further quantification in this analysis is unnecessary. However, it is important to remember that these additional benefits do exist.

SUMMARY

In conclusion, we see that a benefit/cost analysis was useful despite information problems and uncertainties. The expected benefits from lower operation and maintenance costs, and fewer deaths from CVD are greater than the expenditures incurred. The reduction in lead content constitutes an additional, nonmonetary benefit. Since the amount of money to be saved on operations and maintenance alone justifies the expense of treatment for larger systems and for all systems taken as a whole, a regulation requiring

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